accumulate in the filter before the limit of the fan's suction pressure is reached. Here, the requirement is for a graded-efficiency, deep-bed, metal filter with a large storage capacity in the initial layers of the filter for the fluffy sodium aerosol particles, a high efficiency for small particles in most downstream layers of the filter, and the elimination of abrupt interfaces between graded fiber layers where a filter cake might form. This is a different filtration requirement than obtaining high efficiency for low concentrations of small, nonagglomerating particles—instead, the requirement is for uniform particle storage throughout the depth of the filter. Here also, uniform diameter fibers can be used in great depths, as in the DBGF filters, to substitute for the presence of very small-diameter filter fibers.

Other types of metal filters have been constructed by sintering stainless steel powders or fine fibers into a sieve-like structure that functions very much like a conventional pulse-jet-cleaned industrial cloth filter. The metal membrane has an inherent high efficiency for particles greater than a few micrometers, but depends on the formation of a filter cake to obtain high efficiency with submicrometer particles. Clean airflow resistance is high and increases rapidly as cake thickness builds up. It is cleaned periodically by backflow jets of compressed air. Efficiencies are comparable with those of HEPA filters when the sintered metal filters are precoated with filter aids. Because of their high-temperature resistance and ability to handle high concentrations of mineral dusts, these types of filters have been used in nuclear incinerator off-gas cleaning systems, particularly when heat recovery from the hot filtered gases is desired. However, care must be exercised to avoid releasing tar-like combustion products to sintered filters that are operated at high temperature because the tarry material tends to lodge in the pores and turn to cake that cannot be removed by chemical means or by elevating the temperature to the limit of the metal structure.

Another type of sintered filter construction for high-temperature applications has been prepared from a mixture of stainless steel and quartz fibers. The composite material has the same efficiency and pressure drop as HEPA filter glass paper, but has four times the tensile strength and can operate continuously at temperatures up to 500 degrees Celsius (932 degrees Fahrenheit). Applications of the stainless steel and quartz fiber HEPA filter medium have not proceeded beyond the laboratory stage.

## 3.6 DEMISTERS

Liquid droplet entrainment separators are required in the standby air treatment systems of many water-cooled and -moderated power reactors to protect the HEPA filters and activated-charcoal adsorbers from excessive water deposition should a major high-temperature water or stream release occur as a result of an incident involving the core cooling system. Droplet entrainment separators are also used in fuel processing operations to control acid mists generated during dissolving operations and subsequent separation steps.

Entrainment separators consisting of a series of bent plates are widely used in HVAC applications for controlling water carryover from cooling coils and humidifiers; but for nuclear applications, their droplet removal efficiency is inadequate. Therefore, fiber-constraining demisters with a much greater efficiency for small droplets are standard for nuclear service. Entrainment separators utilizing fiber media remove droplets by the same mechanisms that are effective for dry fibrous filters, but they must have the additional and important property of permitting the collected water to drain out of the cell before it becomes clogged. Should clogging occur and the pore spaces fill with water, the pressure drop across the separator will rise and some of the water retained in the pore spaces will be ejected from the air discharge side to create sufficient passages for air to pass through. The ejected water can become airborne again by this mechanism.

Droplets from condensing vapors originate as submicrometer-sized aerosols, but the droplets may grow rapidly to multimicrometer size by acting as condensation centers for additional cooling vapors and by coagulation when the concentration of droplets exceeds 106 ml. Droplets produced by firefighting spray nozzles, containment sprays, and other devices that mechanically atomize liquid jets yield droplets that predominantly range from 50 to more than 1,000 μm in diameter. This range of droplet sizes means that entrainment separators must not only be capable of removing the smallest droplets, but also must resist becoming flooded by the largest droplets and releasing the collected liquid as entrained water.

The USNRC recommends the use of entrainment separators for engineered safety systems when the air may be carrying entrained liquid droplets or a cooling and condensing vapor.[36] Although HEPA filter paper is treated for water repellency, high water loadings rapidly saturate the paper and raise its airflow resistance to a point where gross holes can result. Hot water and steam cause paper to lose its strength and to fail even more rapidly. Therefore, the criteria for entrainment separators used for nuclear service call for (1) at least 99.9 percent retention by weight of entrained water and condensed steam in the size range 1 to 2,000 μm at a delivery rate of 1 L/m$^3$; (2) at least 99 percent retention by count of droplets in the 1- to 10-μm-diameter range; (3) no flooding or water re-entrainment under the above operating conditions; and (4) a temperature tolerance at least to 160 degrees Celsius. An entrainment separator with these characteristics will provide long-term protection for a downstream HEPA filter that would be destroyed in a few minutes without it. Entrainment separators are usually constructed of deep layers of high-porosity metal and glass fibers, either packed or woven into stable batts, and arranged in graded sizes and packing density to give the desired small droplet collection capability with excellent resistance to flooding and re-entrainment.

## 3.7 FILTER SELECTION

Nuclear-grade HEPA filter papers are distinguished from otherwise identical products by their proven resistance to deterioration by radiation. This requirement is spelled out in ASME AG-1[2], which calls for 50 percent retention of original strength and water repellency after exposure to an integrated dose of 6.0 to 6.5 x 1 to 7 rads at a dosage rate not to exceed 2.5 mrad/hr. Because all fabricated filters destined for nuclear service will contain identical or equivalent paper, selection can be based solely on the type of filter construction.

Deep-pleat filters with corrugated aluminum separators have dominated nuclear service both by numbers and years of use, and therefore have the longest and most thoroughly documented performance record. They appear to be stronger than other filter designs, although mini-pleat and separatorless filters are able to meet existing strength requirements in applicable filter standards. Mini-pleat construction has the desirable advantage of packing twice as much paper into a given volume of filter. A disadvantage of the mini-pleat design is the narrowness of the air passages between adjacent pleats, which make it susceptible to premature clogging of the openings by large particles and fibers. This may not be a difficulty when the air being filtered is exceptionally dust-free or when efficient prefilters are employed. Nuclear service experience is sparse or totally lacking for types of filter construction other than deep-pleat filters with corrugated separators, although there may be equivalent experience in nonnuclear applications.

Special nuclear filters are needed when service conditions involve exceptional physical or chemical stress. Although the usual run of filters for nuclear service must provide resistance to short-term exposure to heated air and flame, they are not designed for long-term operation at temperatures exceeding 120 degrees Celsius (248 degrees Fahrenheit). Because the organic sealant between filter pack and filter frame is the least temperature-resistant component, it is possible to increase temperature resistance by substituting a tightly compressed fine-fiber batt for the organic adhesive. In addition, substituting a metal frame for a plywood or composition board increases temperature resistance to the melting point of the glass fibers in the filter medium [500 degrees Celsius (932 degrees Fahrenheit)]. Before this temperature is reached, the organic binder and water-repellent chemicals in the paper will be lost, but this does not adversely affect filtration efficiency or airflow resistance.

The chemical resistance of low-temperature nuclear filters is generally excellent for all dry gases. With high humidity, the presence of HF will cause etching and embrittlement of the glass fibers and ultimate failure of the filter. When droplets of HF or condensed water plus HF gas are present in the airstream, rapid failure of the glass filter paper may be anticipated. Rapid failure (within hrs) also occurs when hydroscopic salts